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(54) **LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD**

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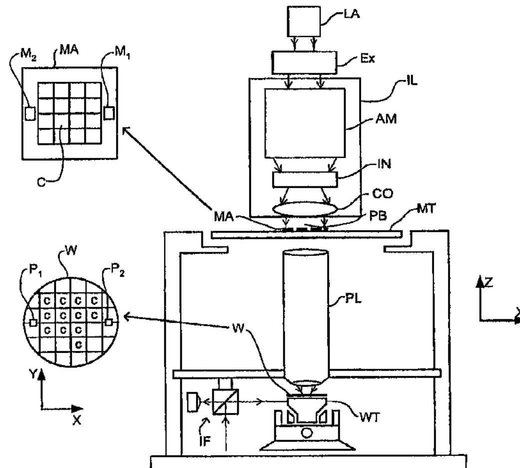
(57) **ABSTRACT**

In a lithographic projection apparatus, a structure surrounds a space between the projection system and a substrate table of the lithographic projection apparatus. A gas seal is formed between said structure and the surface of said substrate to contain liquid in the space.

20 Claims, 7 Drawing Sheets



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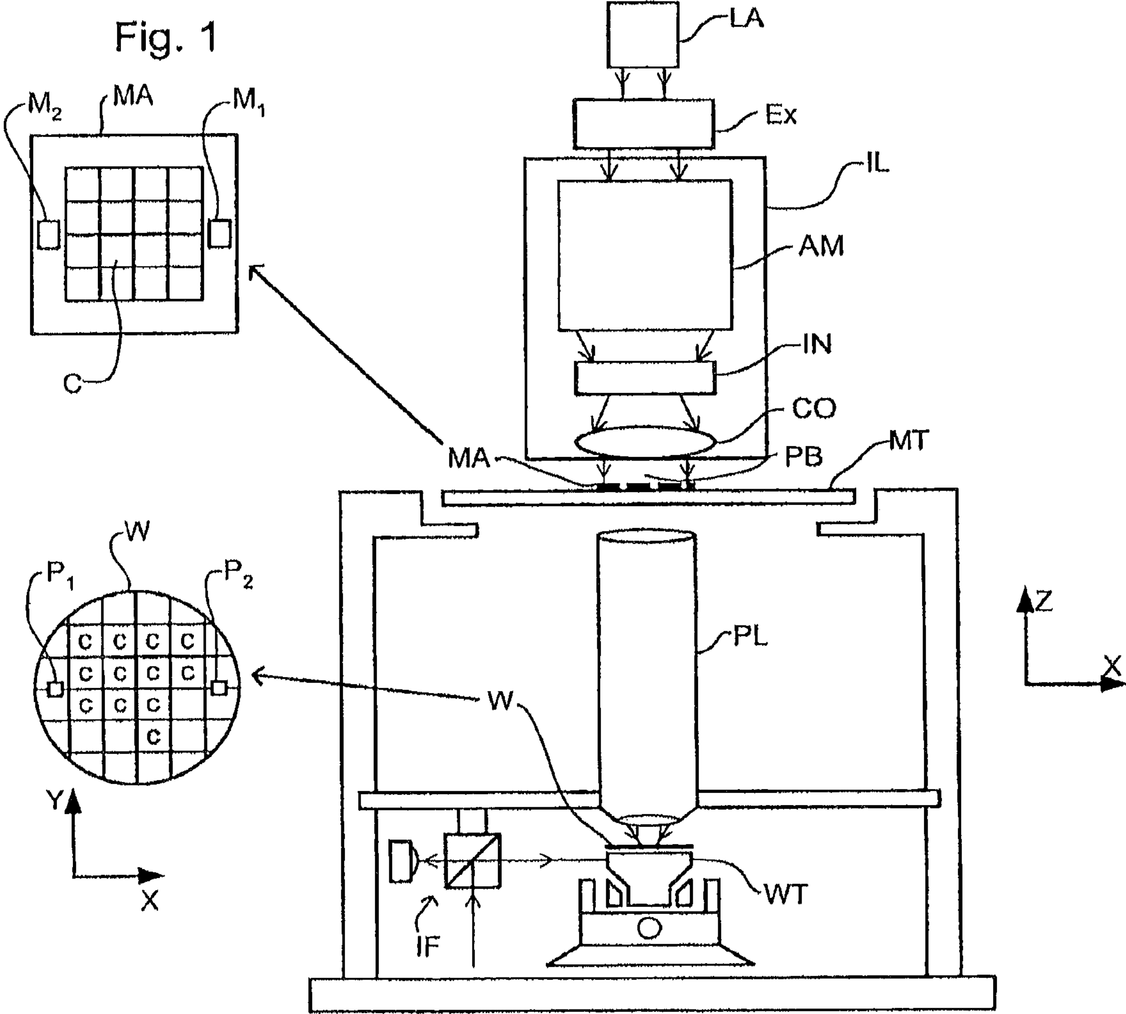


Fig. 1
M2
MA
M1
C
LA
Ex
IL
AM
IN
CO
MA
PB
MT
W
P1
P2
c
Z
X
PL
W
Y
X
WT
IF

Fig. 2

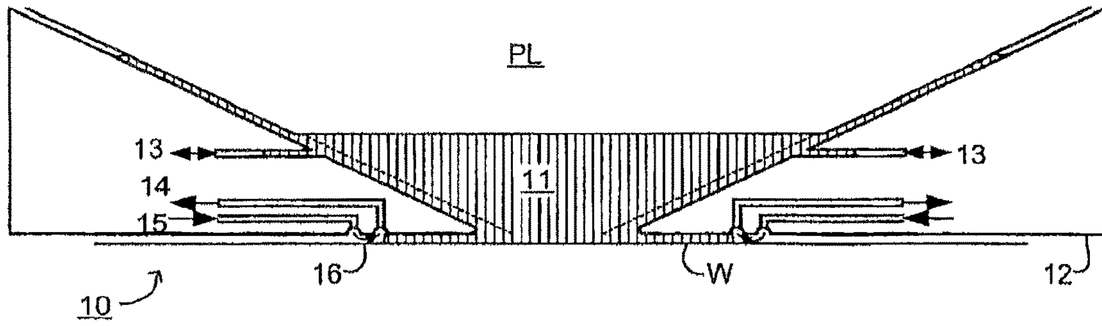


Fig. 3

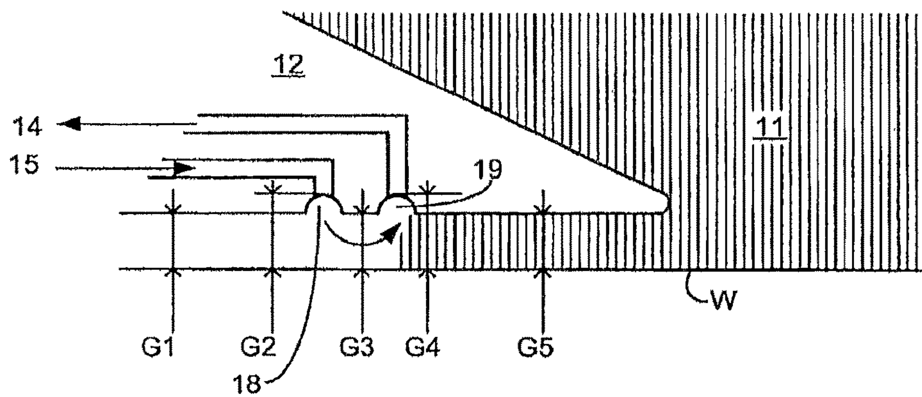
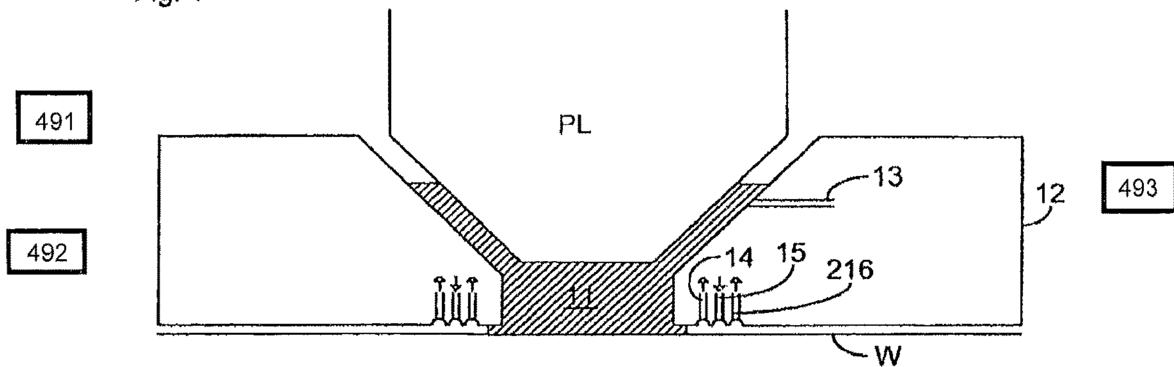


Fig. 4



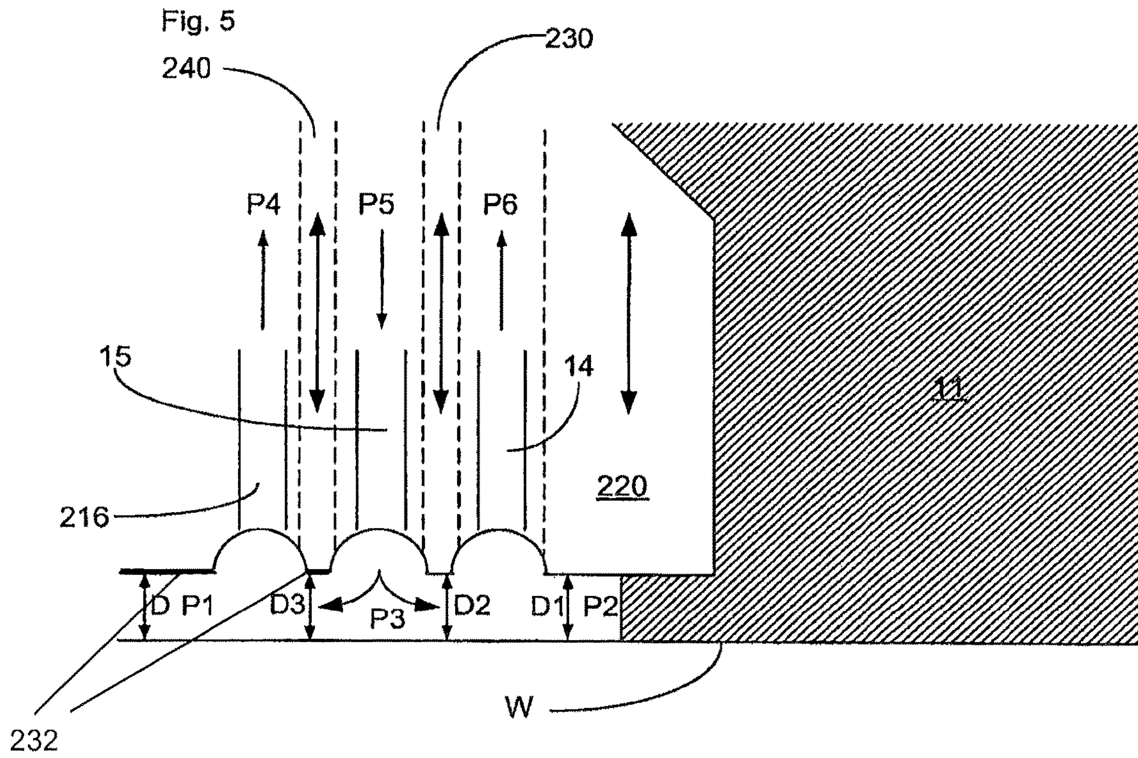


Fig. 5
240
230
P4
P5
P6
15
14
11
220
216
D P1
D3
P3
D2
D1 P2
232
W

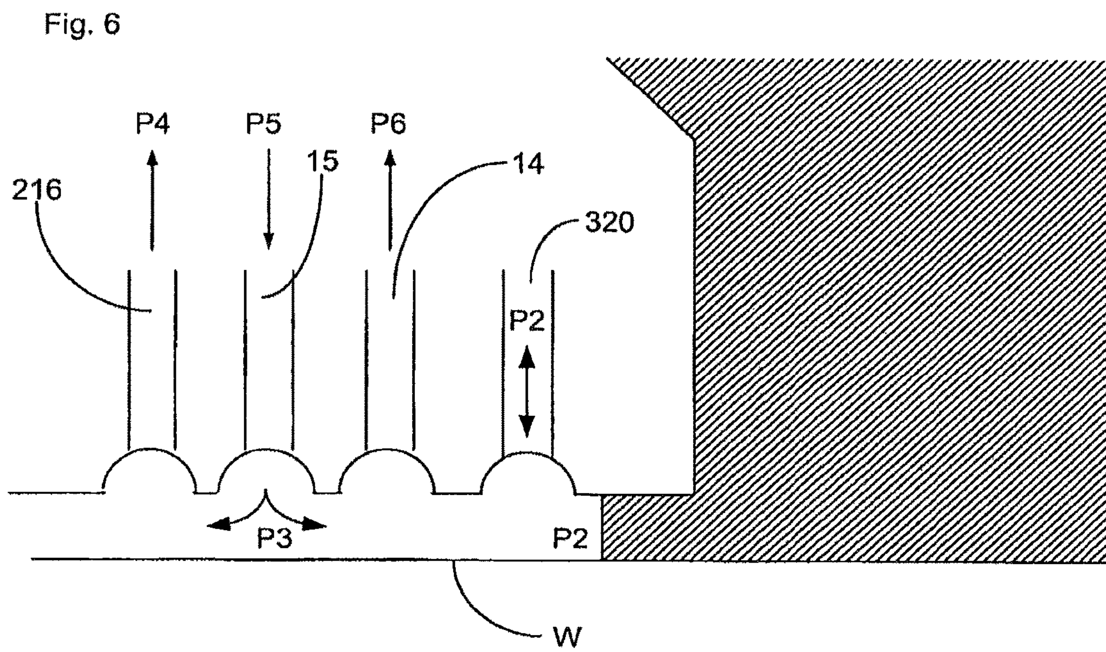


Fig. 6
P4
P5
P6
216
15
14
320
P2
P3
P2
W

Fig. 7

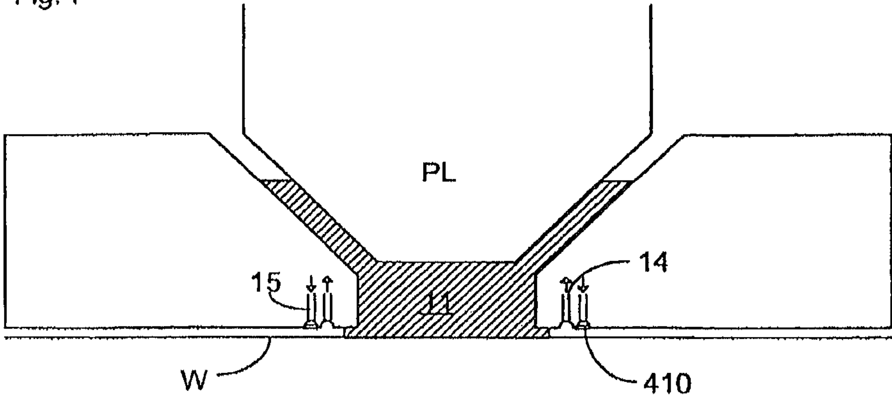


Fig. 8

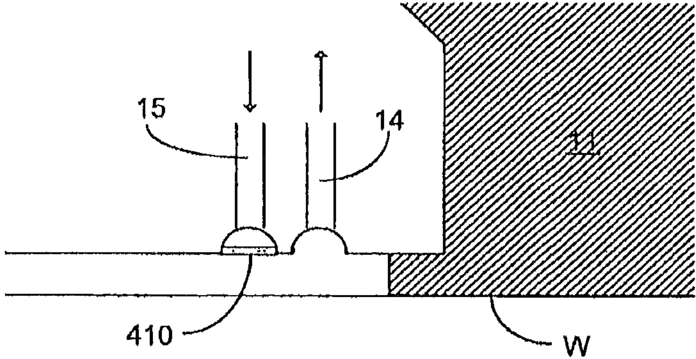
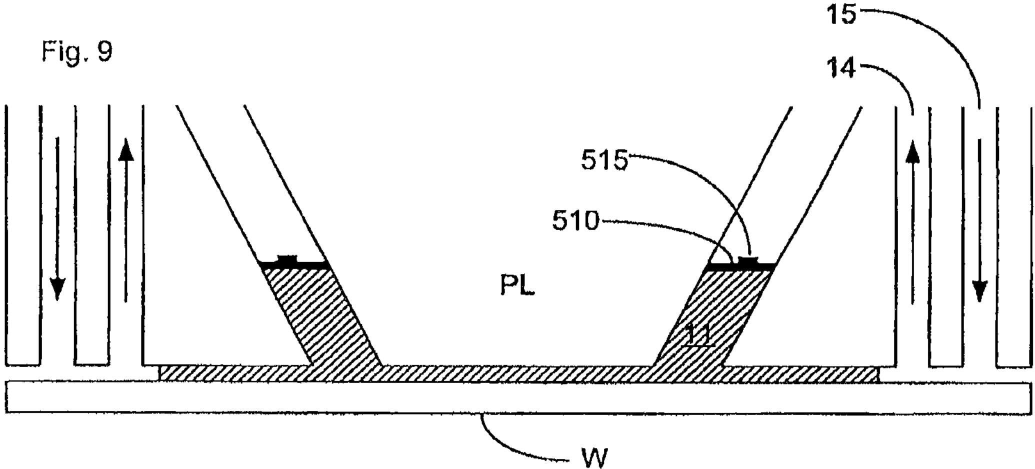


Fig. 9



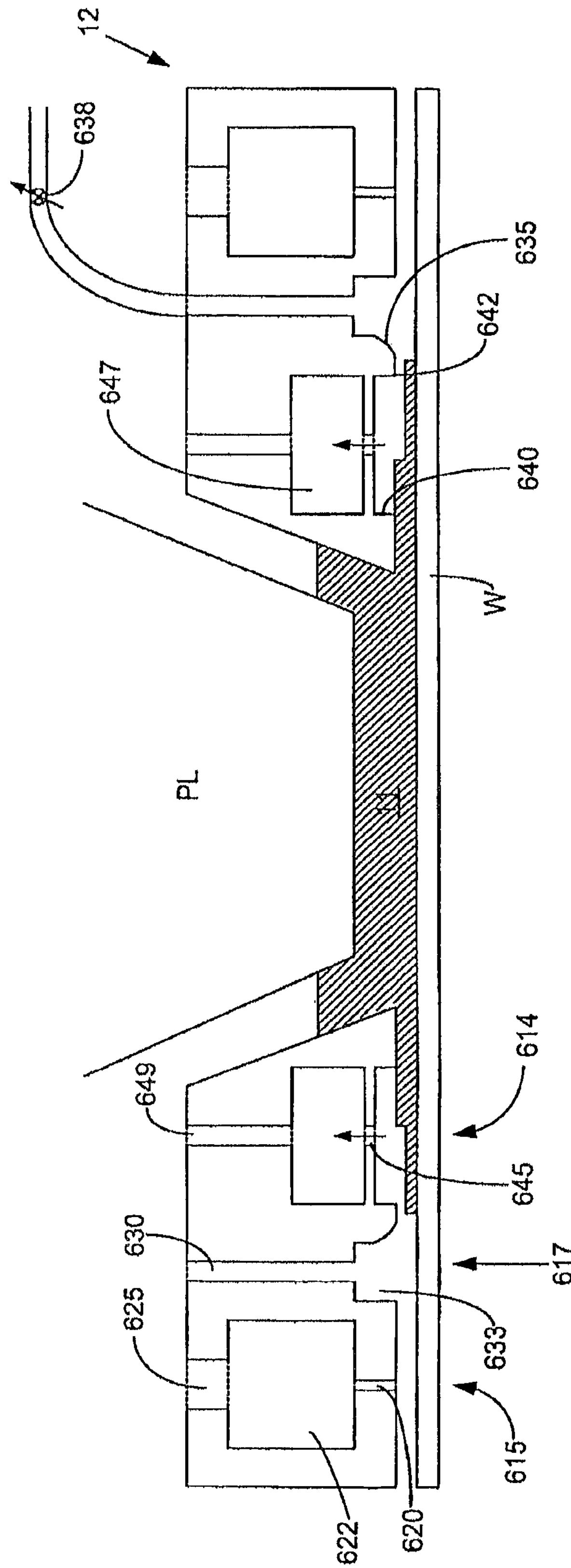


Fig. 10

Fig. 11

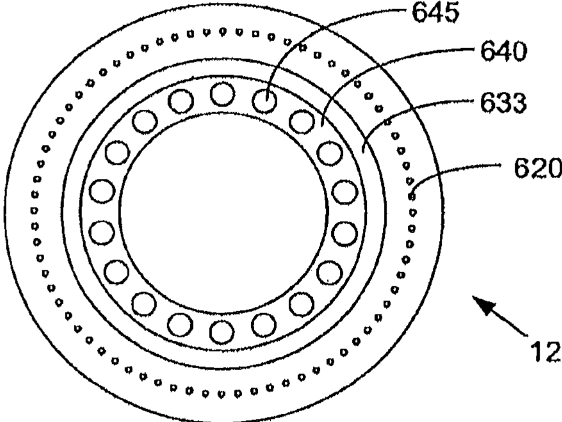


Fig. 12

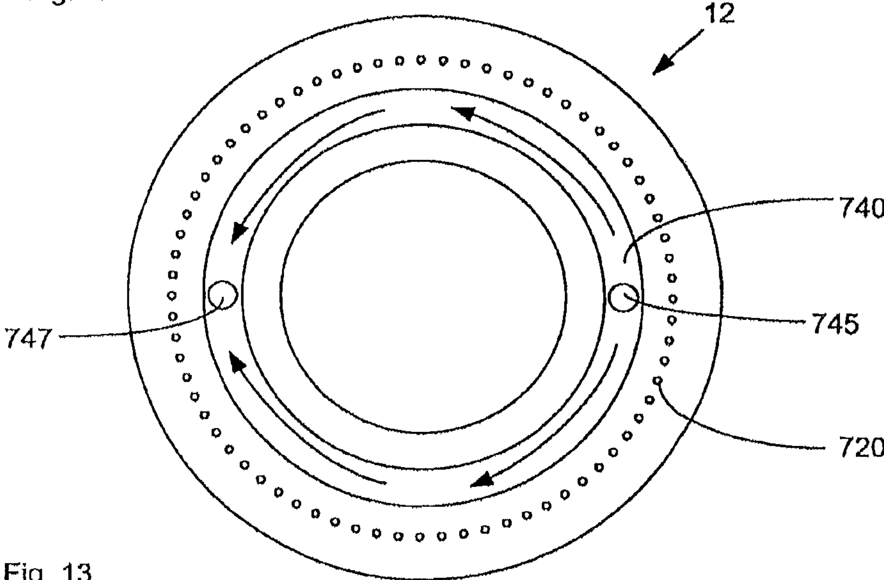
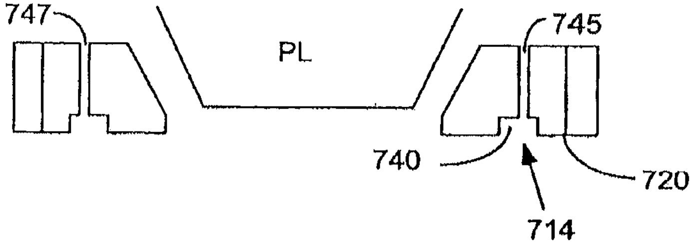


Fig. 13



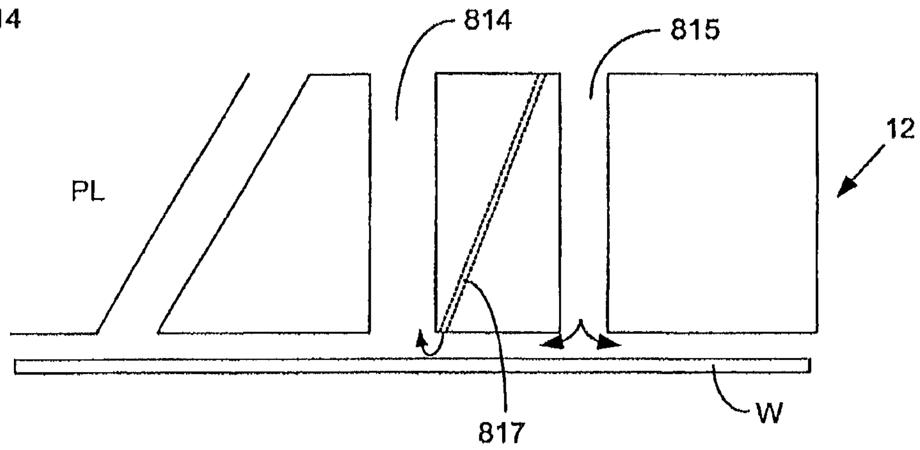


Fig. 14
814
815
12
PL
817
W

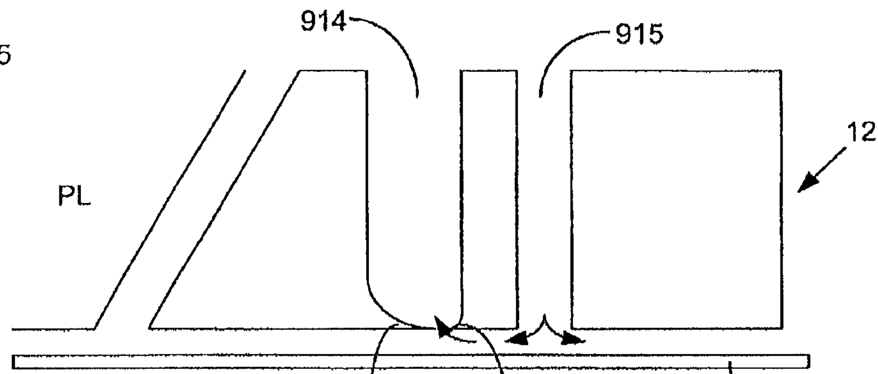


Fig. 15
914
915
12
PL
940
950
W

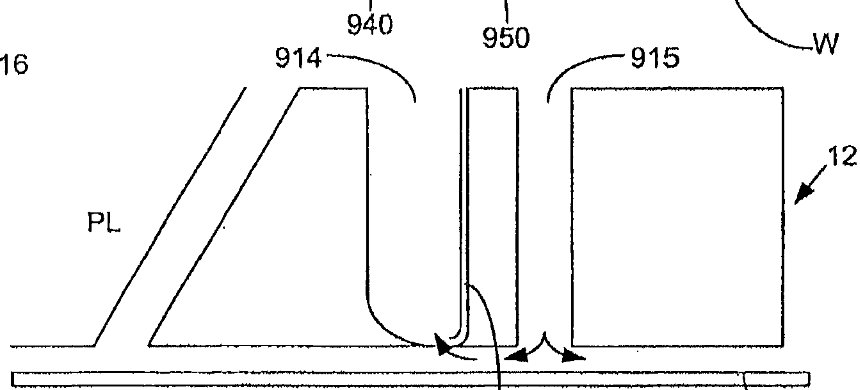


Fig. 16
914
915
12
PL
917
W

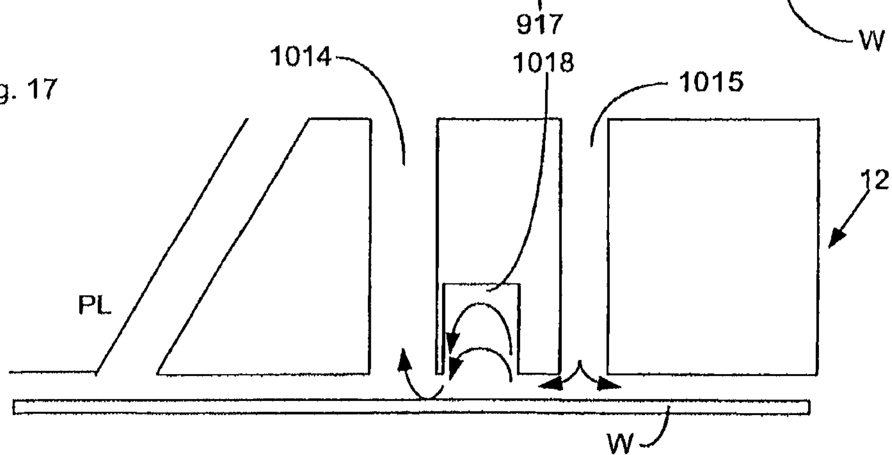


Fig. 17
1014
1018
1015
12
PL
W

LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

This application is a continuation of U.S. patent application Ser. No. 14/743,775, filed Jun. 18, 2015, now allowed, which is a continuation of U.S. patent application Ser. No. 13/722,830, filed Dec. 20, 2012 (now U.S. Pat. No. 9,091,940), which is a continuation of U.S. patent application Ser. No. 13/149,404, filed May 31, 2011 (now U.S. Pat. No. 8,797,503), which is a continuation of U.S. patent application Ser. No. 12/153,276, filed May 15, 2008 (now U.S. Pat. No. 7,982,850), which is a continuation of U.S. patent application Ser. No. 11/239,493, filed Sep. 30, 2005 (now U.S. Pat. No. 7,388,648), which is a continuation of U.S. patent application Ser. No. 10/705,783, filed Nov. 12, 2003 (now U.S. Pat. No. 6,952,253), which claims priority from European patent applications EP 02257822.3, filed Nov. 12, 2002, and EP 03252955.4, filed May 13, 2003, all of the above-referenced applications herein incorporated in their entirety by reference.

FIELD

The present invention relates to immersion lithography.

BACKGROUND

The term “patterning device” as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term “light valve” can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such a patterning device include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning device can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from U.S. Pat. Nos. 5,296,891 and 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in U.S. Pat. No. 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning device as hereabove set forth.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning device may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (e.g. silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion at one time; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus—commonly referred to as a step-and-scan apparatus—each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the “scanning” direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally <1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from U.S. Pat. No. 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array

of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in U.S. Pat. No. 5,969,441 and PCT patent application WO 98/40791, incorporated herein by reference.

It has been proposed to immerse the substrate in a lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system.)

PCT patent application WO 99/49504 discloses a lithographic apparatus in which a liquid is supplied to the space between the projection lens and the wafer. As the wafer is scanned beneath the lens in a −X direction, liquid is supplied at the +X side of the lens and taken up at the −X side.

SUMMARY

Submersing the substrate table in liquid may mean that there is a large body of liquid that must be accelerated during a scanning exposure. This may require additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

There are several difficulties associated with having liquids in a lithographic projection apparatus. For example, escaping liquid may cause a problem by interfering with interferometers and, if the lithographic projection apparatus requires the beam to be held in a vacuum, by destroying the vacuum. Furthermore, the liquid may be used up at a high rate unless suitable precautions are taken.

Further problems associated with immersion lithography may include the difficulty in keeping the depth of the liquid constant and transfer of substrates to and from the imaging position, i.e., under the final projection system element. Also, contamination of the liquid (by chemicals dissolving in it) and increase in temperature of the liquid may deleteriously affect the imaging quality achievable.

In the event of a computer failure or power failure or loss of control of the apparatus for any reason, steps may need to be taken to protect, in particular, the optical elements of the projection system. It may be necessary to take steps to avoid spillage of the liquid over other components of the apparatus.

If a liquid supply system is used in which the liquid has a free surface, steps may need to be taken to avoid the development of waves in that free surface due to forces applied to the liquid supply system. Waves can transfer vibrations to the projection system from the moving substrate.

Accordingly, it may be advantageous to provide, for example, a lithographic projection apparatus in which a space between the substrate and the projection system is filled with a liquid while minimizing the volume of liquid that must be accelerated during stage movements.

According to an aspect, there is provided a lithographic projection apparatus, comprising:

- a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern;
- a substrate table configured to hold a substrate;
- a projection system configured to project the patterned beam onto a target portion of the substrate; and
- a liquid supply system configured to at least partly fill a space between said projection system and said substrate, with a liquid through which said beam is to be projected, said liquid supply system comprising:
- a liquid confinement structure extending along at least a part of the boundary of said space between said projection system and said substrate table, and
- a gas seal between said structure and the surface of said substrate.

A gas seal forms a non-contact seal between the structure and the substrate so that the liquid is substantially contained in the space between the projection system and the substrate, even as the substrate moves under the projection system, e.g. during a scanning exposure.

The structure may be provided in the form of a closed loop, whether circular, rectangular, or other shape, around the space or may be incomplete, e.g., forming a U-shape or even just extending along one side of the space. If the structure is incomplete, it should be positioned to confine the liquid as the substrate is scanned under the projection system.

In an embodiment, the gas seal comprises a gas bearing configured to support said structure. This has an advantage that the same part of the liquid supply system can be used both to bear the structure and to seal liquid in a space between the projection system and the substrate, thereby reducing the complexity and weight of the structure. Also, previous experience gained in the use of gas bearings in vacuum environments can be called on.

In an embodiment, the gas seal comprises a gas inlet formed in a face of said structure that opposes said substrate to supply gas and a first gas outlet formed in a face of said structure that opposes said substrate to extract gas. Further, there may be provided a gas supply to provide gas under pressure to said gas inlet and a vacuum device to extract gas from said first gas outlet. In an embodiment, the gas inlet is located further outward from the optical axis of said projection system than said first gas outlet. In this way, the gas flow in the gas seal is inward and may most efficiently

contain the liquid. In this case, the gas seal may further comprises a second gas outlet formed in the face of the structure which opposes the substrate, the first and second gas outlets being formed on opposite sides of the gas inlet. The second gas outlet helps to ensure minimal escape of gas from the gas inlet into an environment surrounding the structure. Thus, the risk of gas escaping and interfering with, for example, the interferometers or degrading a vacuum in the lithographic apparatus, is minimized.

The liquid supply system may also comprise a sensor configured to measure the distance between the face of the structure and the substrate and/or the topography of the top surface of the substrate. In this way, controller can be used to vary the distance between the face of the structure and the substrate by controlling, for example, the gas seal either in a feed-forward or a feed-back manner.

The apparatus may further comprise a positioning device configured to vary the level of a portion of said face of said structure between the first gas outlet and an edge of the face nearest the optical axis relative to the remainder of the face. This allows a pressure containing the liquid in the space, to be controlled independently of the pressure below the inlet so that the height of the structure over the substrate can be adjusted without upsetting the balance of forces holding liquid in the space. An alternative way of ensuring this is to use a positioning device configured to vary the level of a portion of the face between the first or second gas outlets and the gas inlet relative to the remainder of the face. Those three systems may be used in any combination.

In an embodiment, there is provided a channel formed in the face of the structure located nearer to the optical axis of the projection system than the first gas outlet. The pressure in that channel can be varied to contain the liquid in the space whereas the gas in and out-lets may be used to vary the height of the structure above the substrate so that they only operate to support the structure and have little, if any, sealing function. In this way, it may possible to separate a sealing function and a bearing function of the gas seal.

In an embodiment, a porous member may be disposed over the gas inlet for evenly distributing gas flow over the area of the gas inlet.

In an embodiment, the gas in and out-lets may each comprise a groove in said face of said structure opposing said substrate and a plurality of conduits leading into said groove at spaced locations.

In an embodiment, the gap between said structure and the surface of said substrate inwardly of said gas seal is small so that capillary action draws liquid into the gap and/or gas from the gas seal is prevented from entering the space. The balance between the capillary forces drawing liquid under the structure and the gas flow pushing it out may form a particularly stable seal.

In an embodiment, the liquid supply system is configured to at least partly fill a space between a final lens of the projection system and the substrate, with liquid.

It may also be advantageous to provide, for example, a lithographic projection apparatus in which a space between the substrate and the projection system is filled with a liquid while minimizing a transmission of disturbance forces between the substrate and projection system.

According to an aspect, there is provided a lithographic apparatus, comprising:

a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern;

a substrate table configured to hold a substrate;

a projection system configured to project the patterned beam onto a target portion of the substrate; and

a liquid supply system configured to at least partly fill a space between the final element of said projection system and said substrate with a liquid, wherein said space is in liquid connection with a liquid reservoir through a duct, and the minimum cross sectional area of said duct in a plane perpendicular to the direction of fluid flow is at least

$$\pi\left(\frac{8\Delta V\eta L}{\pi\Delta P_{max}t_{min}}\right)^{1/2},$$

where ΔV is the volume of liquid which has to be removed from said space within time t_{min}, L is the length of the duct, η is viscosity of liquid in said space and ΔP_{max} is the maximum allowable pressure on an element of said projection system.

Liquid may be completely constrained such that it does not have a large free surface for the development of waves, i.e., the space or reservoir is enclosed at the top and the reservoir is full of liquid. This is because the amount of fluid which can flow through the duct in a given time (time of crash measured experimentally) is large enough to avoid damage to the final element of the projection system when the apparatus crashes because the liquid can escape through the duct before pressure in the space builds up to levels at which damage may occur. The liquid escapes when the structure moves relative to the element otherwise the hydrostatic pressure applied to an element of the projection system during relative movement of the element to the structure may damage the element.

According to an aspect, there is provided a lithographic apparatus, comprising:

a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern;

a substrate table configured to hold a substrate;

a projection system configured to project the patterned beam onto a target portion of the substrate;

a liquid supply system configured to at least partly fill a space between said projection system and said substrate with a liquid, said liquid supply system comprising, on a top surface of liquid in said liquid supply system, a wave suppression device configured to suppress development of waves.

In this way, the development of waves can be suppressed by contact of the wave suppression device with a top surface of the liquid. In an embodiment, the wave suppression device comprises a pressure release device. Thus, the liquid can escape from the space in the event of a crash to avoid damaging the element.

An example of a wave suppression device is a flexible membrane. In an embodiment, the wave suppression device may comprise placing a high viscosity liquid which is immiscible with the liquid in the space on the top surface of the liquid in the space. In each of these cases, the pressure release functionality can be provided by the flexibility of the wave suppression device.

According to an aspect, there is provided a device manufacturing method comprising:

providing a liquid to a space between a projection system and a substrate;

projecting a patterned beam of radiation, through said liquid, onto a target portion of the substrate using the projection system; and

forming a gas seal between a liquid confinement structure extending along at least a part of the boundary of said space and the surface of said substrate; or

providing a liquid reservoir in liquid connection with said space through a duct and ensuring that said duct has a minimum cross-sectional area in a plane perpendicular to the direction of flow of liquid of

$$\pi\left(\frac{8\Delta V\eta L}{\pi\Delta P_{max}t_{min}}\right)^{1/2},$$

where ΔV is the volume of liquid which has to be removed from said space within time t_{min}, L is the length of the duct, η is viscosity of liquid in said space and ΔP_{max} is the maximum allowable pressure on an element of said projection system; or

suppressing development of waves on said liquid with a suppression means and optionally, allowing for release of pressure of said liquid.

Although specific reference may be made in this text to the use of the apparatus disclosed herein in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm).

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

FIG. **1** depicts a lithographic projection apparatus according to an embodiment of the invention;

FIG. **2** depicts the liquid reservoir of a first embodiment of the invention;

FIG. **3** is an enlarged view of part of the liquid reservoir of the first embodiment of the invention;

FIG. **4** depicts the liquid reservoir of a second embodiment of the invention;

FIG. **5** is an enlarged view of part of the liquid reservoir of the second embodiment of the invention;

FIG. **6** is an enlarged view of the liquid reservoir of a third embodiment of the present invention;

FIG. **7** depicts the liquid reservoir of a fourth embodiment of the present invention;

FIG. **8** is an enlarged view of part of the reservoir of the fourth embodiment of the present invention;

FIG. **9** depicts the liquid reservoir of a fifth embodiment of the present invention;

FIG. **10** depicts the liquid reservoir of a sixth embodiment of the present invention;

FIG. **11** depicts, in plan, the underside of the seal member of the sixth embodiment;

FIG. **12** depicts, in plan, the underside of the seal member of a seventh embodiment;

FIG. **13** depicts, in cross section, the liquid reservoir of the seventh embodiment;

FIG. **14** depicts, in cross section, the liquid reservoir of an eighth embodiment;

FIG. **15** depicts, in cross section, the liquid reservoir of a ninth embodiment;

FIG. **16** depicts, in cross section, the liquid reservoir of an alternative ninth embodiment; and

FIG. **17** depicts, in cross section, the liquid reservoir of a tenth embodiment.

In the Figures, corresponding reference symbols indicate corresponding parts.

DETAILED DESCRIPTION

Embodiment 1

FIG. **1** schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

a radiation system Ex, IL, for supplying a projection beam PB of radiation (e.g. DUV radiation), which in this particular case also comprises a radiation source LA;

a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;

a projection system ("lens") PL (e.g. a refractive lens system) for imaging an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (e.g. has a transmissive mask). However, in general, it may also be of a reflective type, for example (e.g. with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

The source LA (e.g. an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

It should be noted with regard to FIG. **1** that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in FIG. **1**. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

The depicted apparatus can be used in two different modes:

In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected at one time (i.e. a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed V=Mv, in which M is the magnification of the lens PL (typically, M=¼ or ⅕). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

FIG. **2** shows a liquid reservoir **10** between the projection system PL and a substrate stage. The liquid reservoir **10** is filled with a liquid **11** having a relatively high refractive index, e.g. water, provided via inlet/outlet ducts **13**. The liquid has the effect that the radiation of the projection beam has a shorter wavelength in the liquid than in air or a vacuum, allowing smaller features to be resolved. It is well known that the resolution limit of a projection system is determined, inter alia, by the wavelength of the projection beam and the numerical aperture of the system. The presence of the liquid may also be regarded as increasing the effective numerical aperture. Furthermore, at fixed numerical aperture, the liquid is effective to increase the depth of field.

The reservoir **10** forms a contactless seal to the substrate around the image field of the projection system so that liquid is confined to fill a space between the substrate W surface and the final element of the projection system PL. The reservoir is formed by a seal member **12** positioned below and surrounding the final element of the projection system PL. Liquid is brought into the space below the projection system PL and within the seal member **12**. The seal member **12** extends a little above the final element of the projection system PL and the liquid level rises above the final element so that a buffer of liquid is provided. The seal member **12** has an inner periphery that at the upper end, in an embodiment, closely conforms to the step of the projection system or the final element thereof and may, e.g., be round. At the bottom, the inner periphery closely conforms to the shape of the image field, e.g., rectangular though this need not be the case.

The liquid is confined in the reservoir by a gas seal **16** between the bottom of the seal member **12** and the surface of the substrate W. The gas seal is formed by gas, e.g. air or synthetic air but in an embodiment, N_2 or another inert gas, provided under pressure via inlet **15** to the gap between seal member **12** and the substrate W and extracted via first outlet **14**. The overpressure on the gas inlet **15**, vacuum level on the first outlet **14** and geometry of the gap are arranged so that there is a high-velocity gas flow inwards that confines the liquid. This is shown in more detail in FIG. **3**.

The gas seal is formed by two (annular) grooves **18**, **19** which are connected to the first inlet **15** and first outlet **14** respectively by a series of small conducts spaced around the grooves. The in-and out-lets **14**, **15** may either be a plurality of discrete orifices around the circumference of the seal member **12** or may be continuous grooves or slits. A large (annular) hollow in the seal member may be provided in each of the inlet and outlet to form a manifold. The gas seal may also be effective to support the seal member **12** by behaving as a gas bearing.

Gap G**1**, on the outer side of the gas inlet **15**, is, in an embodiment, small and long so as to provide resistance to gas flow outwards but need not be. Gap G**2**, at the radius of the inlet **15**, is a little larger to ensure a sufficient distribution of gas around the seal member, the inlet **15** being formed by a number of small holes around the seal member. Gap G**3** is chosen to control the gas flow through the seal. Gap G**4** is larger to provide a good distribution of vacuum, the outlet **14** being formed of a number of small holes in the same or similar manner as the inlet **15**. Gap G**5** is small to prevent gas/oxygen diffusion into the liquid in the space, to prevent a large volume of liquid entering and disturbing the vacuum and to ensure that capillary action will always fill it with liquid.

The gas seal is thus a balance between the capillary forces pulling liquid into the gap and the gas flow pushing liquid out. As the gap widens from G**5** to G**4**, the capillary forces decrease and the gas flow increases so that the liquid boundary will lie in this region and be stable even as the substrate moves under the projection system PL.

The pressure difference between the inlet, at G**2** and the outlet at G**4** as well as the size and geometry of gap G**3**, determine the gas flow through the seal **16** and will be determined according to the specific embodiment. However, a possible advantage is achieved if the length of gap G**3** is short and the absolute pressure at G**2** is twice that at G**4**, in which case the gas velocity will be the speed of sound in the gas and cannot rise any higher. A stable gas flow will therefore be achieved.

The gas outlet system can also be used to completely remove the liquid from the system by reducing the gas inlet pressure and allowing the liquid to enter gap G**4** and be sucked out by the vacuum system, which can easily be arranged to handle the liquid, as well as the gas used to form the seal. Control of the pressure in the gas seal can also be used to ensure a flow of liquid through gap G**5** so that liquid in this gap that is heated by friction as the substrate moves does not disturb the temperature of the liquid in the space below the projection system.

The shape of the seal member around the gas inlet and outlet should be chosen to provide laminar flow as far as possible so as to reduce turbulence and vibration. Also, the gas flow should be arranged so that the change in flow

direction at the liquid interface is as large as possible to provide maximum force confining the liquid.

The liquid supply system circulates liquid in the reservoir **10** so that fresh liquid is provided to the reservoir **10**.

The gas seal **16** can produce a force large enough to support the seal member **12**. Indeed, it may be necessary to bias the seal member **12** towards the substrate to make the effective weight supported by the seal member **12** higher. The seal member **12** will in any case be held in the XY plane (perpendicular to the optical axis) in a substantially stationary position relative to and under the projection system but decoupled from the projection system. The seal member **12** is free to move in the Z direction and Rx and Ry.

Embodiment 2

A second embodiment is illustrated in FIGS. **4** and **5** and is the same as the first embodiment except as described below.

In this embodiment a second gas outlet **216** is provided on the opposite side of the gas inlet **15** to the first gas outlet **14**. In this way any gas escaping from the gas inlet **15** outwards away from the optical axis of the apparatus is sucked up by second gas outlet **216** which is connected to a vacuum source **491**. In this way gas is prevented from escaping from the gas seal so that it cannot interfere, for example, with interferometer readings or with a vacuum in which the projection system and/or substrate may be housed.

Another advantage of using the two gas outlet embodiment is that the design is very similar to that of gas bearings previously used in lithographic projection apparatus. Thus the experience gained with those gas bearings can be applied directly to the gas seal of this embodiment. The gas seal of the second embodiment is particularly suitable for use as a gas bearing, as well as a seal means, such that it can be used to support the weight of the seal member **12**.

Advantageously one or more sensors **492** may be provided to either measure the distance between the bottom face of the seal member **12** and the substrate W or the topography of the top surface of the substrate W. A controller **493** may then be used to vary the pressures applied to the gas in- and out-lets **14**, **15**, **216** to vary the pressure P**2** which constrains the liquid **11** in the reservoir and the pressures P**1** and P**3** which support the seal member **12**. Thus the distance D between the seal member **12** and the substrate W may be varied or kept at a constant distance. The same controller may be used to keep the seal member **12** level. The controller may use either a feed forward or a feedback control loop.

FIG. **5** shows in detail how the gas seal can be regulated to control independently the pressure P**2** holding the liquid **11** in the reservoir and P**3** which supports the seal member **12**. This extra control is advantageous because it provides a way of minimizing liquid losses during operation. The second embodiment allows pressures P**2** and P**3** to be controlled independently to account for varying conditions during exposure. Varying conditions might be different levels of liquid loss per unit time because of different scanning speeds or perhaps because the edge of a substrate W is being overlapped by the seal member **12**. This is achieved by providing means for varying the distance to the substrate W of discrete portions of the face of the seal member **12** facing the substrate W. These portions include the portion **220** between the first gas outlet **14** and the edge of the seal member **12** nearest the optical axis, the portion **230** between the gas inlet **15** and the first gas outlet **14** and the portion **240** between the second gas outlet **216** and the gas inlet **15**. These portions may be moved towards and away from the substrate W by the use of piezoelectric actuators for example. That is the bottom face **232** of the seal member **12** may comprise piezoelectric actuators (e.g., stacks) which can be expanded/contracted by the application of a potential difference across them. Other mechanical means could also be used.

The pressure P**3** which is created below the gas inlet **15** is determined by the pressure of gas P**5** applied to the gas inlet **15**, pressures of gas P**6** and P**4** applied to the first and second gas outlets **14** and **216** respectively and by the distance D between the substrate W and the bottom face of the seal member **12** facing the substrate W. Also the horizontal distance between the gas in and out-lets has an effect.

The weight of the seal member **12** is compensated for by the pressure of P**3** so that the seal member **12** settles a distance D from the substrate W. A decrease in D leads to an increase in P**3** and an increase in D will lead to a decrease in P**3**. Therefore this is a self regulating system.

Distance D, at a constant pushing force due to pressure P**3**, can only be regulated by pressures P**4**, P**5** and P**6**. However, the combination of P**5**, P**6** and D creates pressure P**2** which is the pressure keeping the liquid **11** in the reservoir. The amount of liquid escaping from a liquid container at given levels of pressure can be calculated and the pressure in the liquid P_{LIQ} is also important. If P_{LIQ} is larger than P**2**, the liquid escapes from the reservoir and if P_{LIQ} is less than P**2**, gas bubbles will occur in the liquid which is undesirable. It is desirable to try to maintain P**2** at a value slightly less than P_{LIQ} to ensure that no bubbles form in the liquid but also to ensure that not too much liquid escapes as this liquid needs to be replaced. In an embodiment, this can all be done with a constant D. If the distance D**1** between portion **220** and the substrate W is varied, the amount of liquid escaping from the reservoir can be varied considerably as the amount of liquid escaping varies as a square of distance D**1**. The variation in distance is only of the order of 1 mm, in an embodiment 10 μm and this can easily be provided by a piezoelectric stack with an operational voltage of the order of 100V or more.

Alternatively, the amount of liquid which can escape can be regulated by placing a piezoelectric element at the bottom of portion **230**. Changing the distance D**2** is effective to change pressure P**2**. However, this solution might require adjustment of pressure P**5** in gas inlet **15** in order to keep D constant.

Of course the distance D**3** between the lower part of portion **240** and substrate W can also be varied in a similar way and can be used to regulate independently P**2** and P**3**. It will be appreciated that pressures P**4**, P**5** and P**6** and distances D**1**, D**2** and D**3** can all be regulated independently or in combination to achieve the desired variation of P**2** and P**3**.

Indeed the second embodiment is particularly effective for use in active management of the quantity of liquid in the reservoir **10**. The standby situation of the projection apparatus could be, where no substrate W is being imaged, that the reservoir **10** is empty of liquid but that the gas seal is active thereby to support the seal member **12**. After the substrate W has been positioned, liquid is introduced into the reservoir **10**. The substrate W is then imaged. Before the substrate W is removed, the liquid from the reservoir can be removed. After exposure of the last substrate the liquid in the reservoir **10** will be removed. Whenever liquid is removed, a gas purge has to be applied to dry the area previously occupied by liquid. The liquid can obviously be removed easily in the apparatus according to the second embodiment by variation of P**2** while maintaining P**3** constant as

described above. In other embodiments a similar effect can be achieved by varying P**5** and P**6** (and P**4** if necessary or applicable).

Embodiment 3

As an alternative or a further development of the second embodiment as shown in FIG. **6**, a channel **320** may be provided in the face of the seal member **12** facing the substrate W inwardly (i.e. nearer to the optical axis of the projection system) of the first gas outlet **14**. The channel **320** may have the same construction as the gas in- and out-lets **14**, **15**, **216**.

Using the channel **320** pressure P**2** may be varied independently of pressure P**3**. Alternatively, by opening this channel to environmental pressure above the liquid level in the reservoir **10**, the consumption of liquid from the reservoir during operation is greatly reduced. This embodiment has been illustrated in combination with the second embodiment though the channel **320** may be used in combination with any of the other embodiments, in particular the first embodiment. A further advantage is that the gas inlet **15** and first gas outlet **14** (and for certain embodiments second gas outlet **216**) are not disturbed.

Furthermore, although only three elements have been illustrated any number of channels may be incorporated into the face of the seal member **12** facing the substrate W, each channel being at a pressure to improve stiffness, liquid consumption, stability or other property of the liquid supply system.

Embodiment 4

A fourth embodiment which is illustrated in FIGS. **7** and **8** is the same as the first embodiment except as described below. However, the fourth embodiment may also be advantageously used with any of the other embodiments described.

In the fourth embodiment a porous member **410**, in an embodiment porous carbon or a porous ceramic member, is attached to the gas inlet **15** where gas exits the bottom face of the seal member **12**. In an embodiment, the bottom of the porous member is co-planar with the bottom of the seal member. This porous carbon member **410** is insensitive to surfaces which are not completely flat (in this case substrate W) and the gas exiting the inlet **15** is well distributed over the entire exit of the inlet. The advantage gained by using the porous member **410** is also apparent when the seal member **12** is positioned partly over the edge of the substrate W as at this point the surface which the gas seal encounters is uneven.

In a variant of the fourth embodiment, the porous member **410** can be placed in the vacuum channel(s) **14**. The porous member **410** should have a porosity chosen to maintain under pressure while preventing unacceptable pressure loss. This is advantageous when imaging the edge of the substrate W and the gas bearing moves over the edge of the substrate W because although the preload force at the position of the edge might be lost, the vacuum channel is not contaminated with a large and variable amount of gas, greatly reducing variations in the preload and as a consequence variation in flying height and forces on the stage.

Embodiment 5

All of the above described embodiments typically have liquid in the reservoir **10** exposed to a gas, such as air, with a free surface. This is to prevent the final element of the projection system PL from breaking in a case of a crash due to build up of hydrostatic forces on the projection system. During a crash the liquid in the reservoir **10** is unconstrained such that the liquid will easily give, i.e. be forced upwards, when the projection system PL moves against it. The disadvantage of this solution is that surface waves may occur on the free surface during operation thereby transmitting disturbance forces from the substrate W to the projection system PL, which is undesirable.

One way of solving this problem is to ensure that the reservoir **10** is completely contained within a seal member, particularly the upper surface. Liquid is then fed to the reservoir **10** through a duct from a secondary reservoir. That secondary reservoir can have an unconstrained top surface and during a crash liquid is forced through the duct into the second reservoir such that the build up of large hydrostatic forces in the first reservoir **10** on the projection system can be avoided.

In such a closed system the local build up of pressure in the liquid on the projection system is avoided by ensuring that the duct connecting the reservoirs has a cross-sectional area equivalent to a duct with a radius according to the following equation

$$R = \left(\frac{8\Delta V \eta L}{\pi \Delta P t}\right)^{1/4}$$

where R is the duct radius, ΔV is the volume of liquid which has to be removed from the reservoir **10** within time t, L is the length of the duct, η is viscosity of the liquid and ΔP is the pressure difference between the secondary reservoir and the primary reservoir **10**. If an assumption is made that the substrate table can crash with a speed of 0.2 m/sec (measured by experiment) and ΔP_{max} is 10^4 Pa (about the maximum pressure the final element of the project system can withstand before damage results), the pipe radius needed is about 2.5 millimeters for a duct length of 0.2 m. In an embodiment, the effective radius of the duct is at least twice the minimum given by the formula.

An alternative way to avoid the buildup of waves in the liquid in the reservoir while still ensuring that the projection system PL is protected in a crash, is to provide the free surface of the liquid with a suppression membrane **510** on the top surface of the liquid in the reservoir **10**. This solution uses a safety means **515** to allow the liquid to escape in the case of a crash without the build-up of too high a pressure. One solution is illustrated in FIG. **9**. The suppression membrane may be made of a flexible material which is attached to the wall of the seal member **12** or the projection system in such a way that before the pressure in the liquid reaches a predetermined allowed maximum, liquid is allowed to deform the flexible suppression membrane **510** such that liquid can escape between the projection system PL and the suppression membrane **510** or between the suppression membrane and the seal member, respectively. Thus in a crash it is possible for liquid to escape above the safety membrane without damaging the projection system PL. For this embodiment it is obviously desirable to have a space above the suppression membrane of at least the volume of a reservoir **10**. Thus the flexible membrane is stiff enough to prevent the formation of waves in the top surface of the liquid in the reservoir **10** but is not stiff enough to prevent liquid escaping once the liquid reaches a predetermined hydrostatic pressure. The same effect can be achieved by use of pressure valves **515** which allow the free-flow of liquid above a predetermined pressure in combination with a stiffer suppression membrane.

An alternative form of suppression means is to place a high viscosity liquid on the top free surface of the liquid in the reservoir **10**. This would suppress surface wave forma-

tion while allowing liquid to escape out of the way of the projection system PL in the case of a crash. Obviously the high viscosity liquid must be immiscible with the liquid used in the space **10**.

A further alternative for the liquid suppression means **510** is for it to comprise a mesh. In this way the top surface of the liquid can be split into several parts each of smaller area. In this way, development of large surface waves which build up due to resonance and disturb the projection system is avoided because the surface area of the several parts is equal to the mesh opening so that the generation of large surface waves is effectively damped. Also, as the mesh allows flow of liquid through its openings, an effective pressure release mechanism is provided for the protection of the projection system in the case of a crash.

Embodiment 6

A sixth embodiment as illustrated in FIGS. **10** and **11** is the same as the first embodiment except as described below. The sixth embodiment uses several of the ideas in the foregoing embodiments.

As with the other embodiments, the immersion liquid **11** is confined to an area between the projection system PL and the substrate W by a seal member **12**, in this case, positioned below and surrounding the final element of the projection system PL.

The gas seal between the seal member **12** and the substrate W is formed by three types of in-and-out-let. The seal member is generally made up of an outlet **614**, an inlet **615** and a further inlet **617**. These are positioned with the outlet **614** nearest the projection system PL, the further inlet **617** outwardly of the outlet **614** and the inlet **615** furthest from the projection system PL. The inlet **615** comprises a gas bearing in which gas is provided to a plurality of outlet holes **620** in the surface of the seal member **12** facing the substrate W via a (annular) chamber **622**. The force of the gas exiting the outlet **620** both supports at least part of the weight of the seal member **12** as well as providing a flow of gas towards the outlet **614** which helps seal the immersion liquid to be confined to a local area under the projection system PL. A purpose of the chamber **622** is so that the discrete gas supply orifice(s) **625** provide gas at a uniform pressure at the outlet holes **620**. The outlet holes **620** are about 0.25 mm in diameter and there are approximately 54 outlet holes **620**. There is an order of magnitude difference in flow restriction between the outlet holes **620** and the chamber **622** which ensures an even flow out of all of the outlet holes **620** despite the provision of only a small number or even only one main supply orifice **625**.

The gas exiting the outlet holes **620** flows both radially inwardly and outwardly. The gas flowing radially inwardly to and up the outlet **614** is effective to form a seal between the seal member **12** and the substrate W. However, it has been found that the seal is improved if a further flow of gas is provided by a further inlet **617**. Passage **630** is connected to a gas source, for example the atmosphere. The flow of gas radially inwardly from the inlet **615** is effective to draw further gas from the further inlet **617** towards the outlet **614**.

A (annular) groove **633** which is provided at the end of the passage **630** (rather than a series of discrete inlets) ensures that the sealing flow of gas between the inner most edge of the groove **633** and the outlet **614** is even around the whole circumference. The groove is typically 2.5 mm wide and of a similar height.

The inner most edge **635** of the groove **633** is, as illustrated, provided with a radius to ensure smooth flow of the gas through passage **630** towards the outlet **614**.

The outlet **614** also has a continuous groove **640** which is approximately only 0.7 mm high but 6 to 7 mm wide. The outer most edge **642** of the groove **640** is provided as a sharp, substantially 90°, edge so that the flow of gas, in particular the flow of gas out of further inlet **617** is accelerated to enhance the effectiveness of the gas seal. The groove **640** has a plurality of outlet holes **645** which lead into a (annular) chamber **647** and thus to discrete outlet passage **649**. In an embodiment, the plurality of outlet holes **645** are approximately 1 mm in diameter such that liquid droplets passing through the outlet holes **645** are broken up into smaller droplets.

The effectiveness of liquid removal of the seal member **12** can be adjusted by an adjustable valve **638** connected to the further inlet **617**. The valve **638** is effective to adjust the flow through further inlet **617** thereby to vary the effectiveness of liquid removal of the gas seal **12** through outlet **614**.

In an embodiment, the overall diameter of the seal member is of the order of 100 mm.

FIG. **11** shows, in plan, the underside of the seal member **12** of FIG. **10**. As can be seen, the inlet **615** is provided as a plurality of discrete inlet holes **620**. This is advantageous over the use of a groove for the main inlet **615** because a groove as a gas bearing has a capacity (because of the compressible nature of gas) such that vibrations can be set up in such a system. Small inlet holes **620** have a lower volume of gas in them and therefore suffer less from problems arising from capacity.

The use of a further inlet **617** in the form of a groove **633** can be used to ensure a continuous gas flow around the whole periphery of the seal member **12** which would not necessarily be possible when only using discrete inlet holes **620**. The provision of the outlets **645** as discrete entities is not a problem because of the provision of the groove **640** which is effective, like chambers **647** and **622**, to even out the flow.

The inlets for liquid are not illustrated in the seal member **12** of FIGS. **10** and **11**. The liquid may be provided in the same manner as illustrated in the foregoing embodiments or, alternatively, any of the liquid inlets and outlets as described in European patent application nos. EP 03256820.6 and EP 03256809.9.

Embodiment 7

A seventh embodiment is similar to the sixth embodiment except as described below. FIG. **12** is a plan view of the underside of the seal member **12** similar to that shown in FIG. **11**. In FIG. **12** the seal member is not provided with a further inlet as in the sixth embodiment though this can optionally be added. FIG. **13** shows a cross-section.

The seal member **12** of the seventh embodiment comprises a gas bearing formed by inlet holes **720** and which is of the same overall design as the sixth embodiment. An outlet **714** comprises a (annular) groove **740** with only two passages **745**, **747** which lead to a gas source and a vacuum source respectively. In this way a high speed flow of gas from the gas source connected to passage **745** towards the vacuum source connected to passage **747** can be established. With this high speed flow of gas, immersion liquid may be drained more effectively. Furthermore, by creating a larger restricted vacuum flow in the vacuum chamber, flow fluctuations due to variations in the height of the seal member **12** above the substrate W or other leakage sources in the surface will not influence the vacuum chamber pressure providing a preload for the gas bearing.

Embodiment 8

An eighth embodiment will be described in relation to FIG. **14** and is the same as the first embodiment except as described below.

As can be seen from FIG. **14**, the eighth embodiment has a seal member **12** with an inlet **815** and an outlet **814** just like the first embodiment. However, a further inlet **817** is provided which is arranged so that a jet of gas can be formed which increases the velocity of the gas on the surface of the substrate W below or radially outwardly of the outlet **814** so that immersion liquid is more effectively removed from the surface of the substrate W. The further inlet **817** has an exit provided by a nozzle which is directed towards the substrate W at an angle radially inwardly towards the projection system PL. Thus, the otherwise laminar gas flow (with a Reynolds number of around 300) between the inlet **815** and the outlet **814** and which has a simple parabolic speed distribution with a zero speed on the surface of the substrate, which may not be able to remove the last few micrometers of liquid film from the substrate, can be improved because the further inlet **817** ensures that gas with a higher gas velocity is in contact with the substrate surface.

From FIG. **14** it can be seen that the exit nozzle of the further inlet **817** is provided radially outwardly of the outlet **814** but closer to the outlet **814** than to the inlet **815**.

Embodiment 9

A ninth embodiment is illustrated in FIGS. **15** and **16** and is the same as the first embodiment except as described below.

In the ninth embodiment, the mouth of outlet **914** in the bottom surface of the seal member **12** which faces the substrate W, is modified to increase the velocity of gas into the outlet **914**. This is achieved by reducing the size of the mouth of the inlet **914** while keeping the passageway of the outlet **914** the same size. This is achieved by providing a smaller mouth by extending material of the seal member **12** towards the center of the passage to form an outer additional member **950** and an inner additional member **940**. The outer additional member **950** is smaller than the inner additional member **940** and the gap between those two members **940**, **950** is, in an embodiment, approximately 20 times smaller than the remainder of the outlet **914**. In an embodiment, the mouth is approximately 100 to 300 μm in width.

In FIG. **16** a further alternative version of the ninth embodiment is depicted in which a further inlet **917** similar to the further inlet **817** of the eight embodiment is provided. However, in this case the further inlet **917** provides a jet of flow substantially parallel to the surface of the substrate W so that the gas entering the mouth of the outlet **914** is accelerated.

Embodiment 10

A tenth embodiment is illustrated in FIG. **17** and is the same as the first embodiment except as described below.

In the tenth embodiment, the efficiency of liquid removal may be improved by increasing the velocity of gas on the surface of the substrate W along the same principles as in the eight embodiment. Gas leaving inlets **1015** and moving radially inwardly towards an outlet **1014** passes underneath a (annular) groove **1018**. The effect of the groove, as illustrated, is for the gas to enter the groove on its radially outer most side and to exit it, with an angle towards the substrate W, on the radially inward side. Thus, the speed of the gas on the surface of the substrate W at the entrance to the outlet **1014** is increased and liquid removal efficiency is improved.

It will be clear that features of any embodiment can be used in conjunction with some or all features of any other embodiment.

In an aspect, there is provided a lithographic projection apparatus, comprising: a support structure configured to hold a patterning device and movable in a scanning direction, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate and movable in a scanning direction; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid confinement structure extending along at least a part of a boundary of a space between the projection system and the substrate table, the space having a cross-sectional area smaller than the area of the substrate, the liquid confinement structure positioned adjacent a final surface of the projection system and comprising: a first inlet to supply liquid, through which the patterned beam is to be projected, to the space, a first outlet to remove liquid after the liquid has passed under the projection system, a second inlet formed in a face of the structure, the face arranged to oppose a surface of the substrate, and located radially outward, with respect to an optical axis of the projection system, of the space to supply gas, and a second outlet formed in the face and located radially outward, with respect to an optical axis of the projection system, of the second inlet to remove gas.

In an aspect, the area has a periphery conforming to a shape of an image field of the projection system. In an aspect, the inlet is configured to supply the liquid at a first side of the projection system and the outlet is configured to remove the liquid at a second side of the projection system as the substrate is moved under the projection system in a direction from the first side to the second side. In an aspect, the second inlet, the second outlet, or both, extend around the final surface of the projection system. In an aspect, the second inlet, the second outlet, or both, comprise a groove in the face. In an aspect, the groove is circular and extends around the space. In an aspect, the structure forms a closed loop around the space. In an aspect, the apparatus further comprises a porous member disposed over the second inlet to evenly distribute gas flow over the area of the second inlet.

In an aspect, there is provided a lithographic projection apparatus, comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid confinement structure extending along at least a part of a boundary of a space between the projection system and the substrate table, the space having a cross-sectional area smaller than the area of the substrate, the liquid confinement structure positioned adjacent a final surface of the projection system and comprising: a first inlet configured to supply a liquid, through which the patterned beam is to be projected, to the space, a second inlet configured to supply gas and formed in a face of the structure, the face arranged to oppose a surface of the substrate and the second inlet located radially outward, with respect to an optical axis of the projection system, of and substantially around the space, and a second outlet configured to remove gas and formed in the face, the second outlet located radially outward, with respect to an optical axis of the projection system, of and substantially around the second inlet.

In an aspect, the area has a periphery conforming to a shape of an image field of the projection system. In an

aspect, the first inlet is configured to supply the liquid at a first side of the projection system and the apparatus further comprises a second outlet configured to remove the liquid at a second side of the projection system as the substrate is moved under the projection system in a direction from the first side to the second side. In an aspect, the second inlet, the second outlet, or both, comprise a groove in the face. In an aspect, the groove is circular. In an aspect, the support structure and the substrate table are movable in a scanning direction to expose the substrate. In an aspect, the apparatus further comprises a porous member disposed over the second inlet to evenly distribute gas flow over the area of the second inlet.

In an aspect, there is provided a lithographic projection apparatus, comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid confinement structure extending along at least a part of a boundary of a space between the projection system and the substrate table, the space having a cross-sectional area smaller than the area of the substrate, the liquid confinement structure positioned adjacent a final surface of the projection system and comprising: a first inlet configured to supply a liquid, through which the patterned beam is to be projected, to the space, a second inlet configured to supply gas and formed in a face of the structure, the face arranged to oppose a surface of the substrate and the second inlet located radially outward, with respect to an optical axis of the projection system, of the space and having a porous member to evenly distribute gas flow over an area of the second inlet.

In an aspect, the apparatus further comprises a second outlet configured to remove gas and formed in the face, the second outlet located radially outward, with respect to an optical axis of the projection system, of the second inlet. In an aspect, the first inlet is configured to supply the liquid at a first side of the projection system and the apparatus further comprises a second outlet configured to remove the liquid at a second side of the projection system as the substrate is moved under the projection system in a direction from the first side to the second side. In an aspect, the support structure and the substrate table are movable in a scanning direction to expose the substrate. In an aspect, the structure forms a closed loop around the space.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid supply system configured to at least partly fill a space between said projection system and said substrate, with a liquid through which said beam is to be projected, said liquid supply system comprising: a liquid confinement structure extending along at least a part of the boundary of said space, and a seal between said structure and the surface of said substrate.

In an aspect, said seal comprises a gas inlet formed in a face of said structure that opposes said substrate to supply gas and a gas outlet formed in a face of said structure that opposes said substrate to extract gas. In an aspect, said gas seal comprises a gas supply to provide gas under pressure to said gas inlet and a vacuum device to extract gas from said gas outlet. In an aspect, said gas inlet is located radially further from the optical axis of said projection system than is said gas outlet. In an aspect, said gas inlet and said gas outlet each comprise a groove in said face of said structure opposing said substrate and a plurality of conduits leading into said groove at spaced locations. In an aspect, said gas inlet and said gas outlet each comprises a manifold between said conduits and a gas source and a vacuum pump respectively. In an aspect, the gap between said structure and the surface of said substrate inwardly of said gas seal is small so that capillary action at least one of draws liquid into the gap and prevents gas from said gas seal entering said space. In an aspect, said structure forms a closed loop around said space between said projection system and said substrate. In an aspect, said structure has an inner periphery closely conforming to the shape of the image field of said projection system. In an aspect, said substrate table further comprises a cover plate surrounding said substrate, in use, and having an upper surface substantially coplanar therewith. In an aspect, the apparatus further comprises a controller configured to control the gas pressure in said gas seal to control the stiffness between said structure and said substrate. In an aspect, said structure is stationary relative to said projection system. In an aspect, said support structure and said substrate table are movable in a scanning direction to expose said substrate. In an aspect, said liquid supply system comprises at least one inlet to supply said liquid onto the substrate and at least one outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, said liquid supply system is configured to at least partly fill a space between a final lens of said projection system and said substrate, with said liquid.

In an aspect, there is provided an immersion lithographic projection apparatus, comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid confinement structure extending along at least part of the boundary of a space bounded by the periphery of a localized area on the surface of said substrate and said surface of said substrate, said space configured to contain a liquid through which said beam is projected and said structure substantially sealing at least part of said space.

In an aspect, said support structure and said substrate table are movable in a scanning direction to expose said substrate. In an aspect, said structure comprises at least one inlet to supply said liquid onto the substrate and at least one outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, the apparatus comprises a gas seal between said structure and said substrate. In an aspect, said gas seal comprises a gas inlet formed in a face of said structure that opposes said substrate to supply gas and a gas outlet formed in a face of said structure that opposes said substrate to extract gas.

In an aspect, there is provided a device manufacturing method comprising: providing a liquid to fill a space between a substrate and a projection system, a liquid confinement structure extending along at least a part of the boundary of said space; forming a gas seal between said structure and the surface of said substrate; and projecting a patterned beam of radiation, through said liquid, onto a target portion of the substrate.

In an aspect, forming said gas seal comprises supplying a gas through a gas inlet formed in a face of said structure that opposes said substrate and extracting gas through a gas outlet formed in a face of said structure that opposes said substrate. In an aspect, the method comprises supplying said

gas at a position radially further from the optical axis of said projection system than said extracting of gas. In an aspect, the method comprises maintaining the gap between said structure and the surface of said substrate inwardly of said gas seal small so that capillary action at least one of draws liquid into the gap and prevents gas from said gas seal entering said space. In an aspect, said structure forms a closed loop around said space between said projection system and said substrate. In an aspect, said structure has an inner periphery closely conforming to the shape of the image field of said projection system. In an aspect, the method further comprises controlling the gas pressure in said gas seal to control the stiffness between said structure and said substrate. In an aspect, the method comprises moving said support structure and said substrate table in a scanning direction to expose said substrate. In an aspect, the method comprises supplying said liquid onto the substrate and removing said liquid after said liquid has passed under said projection system. In an aspect, providing a liquid to fill comprises providing a liquid to fill a space between a substrate and a final lens of said projection system.

In an aspect, there is provided an immersion lithographic projection apparatus comprising: a support structure configured to hold a patterning device and movable in a scanning direction, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate and movable in a scanning direction; a projection system configured to project the patterned beam onto a target portion of the substrate using a scanning exposure; a liquid confinement structure that substantially seals at least part of a space bounded by a surface of said substrate and the boundary of a portion of said surface; and a liquid inlet to provide a liquid, through which said beam is projected, to said space.

In an aspect, said inlet is configured to supply said liquid onto the substrate and comprising an outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, the apparatus comprises a gas seal between said structure and said surface of said substrate. In an aspect, said gas seal comprises a gas inlet formed in a face of said structure that opposes said surface to supply gas and a gas outlet formed in a face of said structure that opposes said surface to extract gas. In an aspect, said boundary conforms to a shape of an image field of said projection system.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device and movable in a scanning direction, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate and movable in a scanning direction; a projection system configured to project the patterned beam onto a target portion of the substrate using a scanning exposure; a liquid confinement structure having an aperture having a cross-sectional area smaller than a surface area of said substrate; a seal between said structure and said substrate; and a liquid inlet to provide a liquid, through which said beam is projected, to said aperture.

In an aspect, said inlet is configured to supply said liquid onto the substrate and comprising an outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, said seal is a gas seal. In an aspect, said gas seal comprises a gas inlet formed in a face of said structure that opposes a surface of said substrate to supply gas and a gas outlet formed in a face of said structure that opposes said surface of said substrate to extract gas. In an aspect, said aperture has a periphery conforming to a shape of an image field of said projection system.

In an aspect, there is provided an immersion lithographic projection apparatus comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; a liquid confinement structure that can substantially confine all of a liquid provided to an area of a radiation-sensitive surface of said substrate under said projection system, said area being smaller than the entire area of said substrate surface; and a liquid inlet to provide a liquid to said area and between said projection system and said substrate surface.

In an aspect, said support structure and said substrate table are movable in a scanning direction to expose said substrate. In an aspect, said inlet is configured to supply said liquid to said substrate surface and comprising an outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, said inlet supplies said liquid at a first side of said projection system and said outlet removes said liquid at a second side of said projection system as said substrate is moved under said projection system in a direction from the first side to the second side. In an aspect, said structure comprises a gas seal. In an aspect, said gas seal comprises a gas inlet formed in a face of said structure that opposes said substrate surface and a gas outlet formed in a face of said structure that opposes said substrate surface. In an aspect, said area has a periphery conforming to a shape of an image field of said projection system.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid supply system configured to at least partly fill a space between said projection system and said substrate, with a liquid through which said beam is to be projected, said liquid supply system comprising: a liquid confinement structure extending along at least a part of the boundary of said space between said projection system and said substrate table, and a gas seal between said structure and the surface of said substrate.

In an aspect, said gas seal comprises a gas bearing configured to support said structure over said substrate. In an aspect, said gas seal comprises a gas inlet formed in a face of said structure that opposes said substrate to supply gas and a first gas outlet formed in a face of said structure that opposes said substrate to extract gas. In an aspect, said gas seal comprises a gas supply to provide gas under pressure to said gas inlet and a vacuum device to extract gas from said first gas outlet. In an aspect, the apparatus further comprises a further inlet connected to a gas source and positioned between said first gas outlet and said gas inlet. In an aspect, said further inlet comprises a continuous annular groove in a surface of said structure facing said substrate. In an aspect, a radially innermost corner of said groove has a radius. In an aspect, said first gas outlet comprises a continuous annular groove in a surface of said structure facing said substrate. In an aspect, at least one of said first gas outlet and said gas inlet comprise a chamber between a gas supply and a vacuum device respectively and a respective opening of said at least one of said first gas outlet and said gas inlet in said surface, wherein said chamber provides a lower flow restriction than said opening. In an aspect, said gas inlet comprises

a series of discrete openings in a surface of said structure facing said substrate. In an aspect, said first gas outlet comprises a groove in said face of said structure opposing said substrate, a first passage in said groove connected to a vacuum source and a second passage in said groove connected to a gas supply. In an aspect, a porous member is disposed over said gas inlet to evenly distribute gas flow over the area of said gas inlet. In an aspect, a porous member is disposed over said first gas outlet to evenly distribute gas flow over the area of said first gas outlet. In an aspect, said structure further comprises a second gas outlet formed in said face of said structure that opposes said substrate, said first and second gas outlets being formed on opposite sides of said gas inlet. In an aspect, the apparatus further comprises a positioning device configured to vary the level of a portion of said face between said second gas outlet and said gas inlet relative to the remainder of said face. In an aspect, the apparatus further comprises a positioning device configured to vary the level of a portion of said face between said first gas outlet and said gas inlet relative to the remainder of said face. In an aspect, the apparatus further comprises a positioning device configured to vary the level of a portion of said face between said first gas outlet and an edge of said face nearest said optical axis relative to the remainder of said face. In an aspect, said gas seal comprises a channel formed in said face and located nearer to the optical axis of the projection system than said first gas outlet. In an aspect, said channel is a second gas inlet. In an aspect, said channel is open to the environment above the level of liquid in said space. In an aspect, said gas inlet is located further outward from the optical axis of said projection system than is said first gas outlet. In an aspect, said gas inlet and said first gas outlet each comprise a groove in said face of said structure opposing said substrate and a plurality of conduits leading into said groove at spaced locations. In an aspect, the apparatus further comprises a sensor configured to measure the distance between said face of said structure and at least one of said substrate and the topography of said substrate. In an aspect, the apparatus further comprises a controller configured to control the gas pressure in said gas seal to control at least one of the stiffness between said structure and said substrate and the distance between said structure and said substrate. In an aspect, the gap between said structure and the surface of said substrate inwardly of said gas seal is small so that capillary action at least one of draws liquid into the gap and reduces gas from said gas seal entering said space. In an aspect, said structure forms a closed loop around said space between said projection system and said substrate. In an aspect, the apparatus comprises on a top surface of liquid in said liquid supply system, a wave suppression device configured to suppress development of waves. In an aspect, said wave suppression device comprises a pressure release device. In an aspect, the apparatus comprises a further gas inlet formed in a face of said structure that opposes said substrate, disposed between said first gas outlet and said gas inlet and angled radially inwardly towards an optical axis of the projection system to provide a jet of gas. In an aspect, the apparatus comprises a groove formed in a face of said structure that opposes said substrate and disposed between said first gas outlet and said gas inlet. In an aspect, said liquid supply system comprises at least one inlet to supply said liquid onto the substrate and at least one outlet to remove said liquid after said liquid has passed under said projection system. In an aspect, said support structure and said substrate table are movable in a scanning direction to expose said substrate. In an aspect, said liquid supply system is configured to at least partly fill a space between a final lens of said projection system and said substrate, with said liquid.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; and a liquid supply system configured to at least partly fill a space between said projection system and said substrate with a liquid, wherein said space is in liquid connection with a liquid reservoir through a duct, and the minimum cross sectional area of said duct in a plane perpendicular to the direction of fluid flow is at least

$$\pi\left(\frac{8\Delta V\eta L}{\pi\Delta P_{max}t_{min}}\right)^{1/2}$$

where ΔV is the volume of liquid which has to be removed from said space within time t_{min}, L is the length of the duct, η is viscosity of liquid in said space and ΔP_{max} is the maximum allowable pressure on an element of said projection system.

In an aspect, said space is enclosed such that when liquid is present in said space, said liquid has no free upper surface.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate; a projection system configured to project the patterned beam onto a target portion of the substrate; a liquid supply system configured to at least partly fill a space between said projection system and said substrate with a liquid, said liquid supply system comprising on a top surface of liquid in said liquid supply system, a wave suppression device configured to suppress development of waves.

In an aspect, said wave suppression device comprises a flexible membrane. In an aspect, said wave suppression device comprises a mesh such that the maximum area of said top surface of said liquid is equal to the mesh opening. In an aspect, said wave suppression device comprises a high viscosity liquid which is immiscible with said liquid. In an aspect, said wave suppression device comprises a pressure release device. In an aspect, said pressure release device comprises a safety valve configured to allow the passage therethrough of liquid above a certain pressure.

In an aspect, there is provided a lithographic projection apparatus comprising: a support structure configured to hold a patterning device and movable in a scanning direction, the patterning device configured to pattern a beam of radiation according to a desired pattern; a substrate table configured to hold a substrate and movable in a scanning direction; a projection system configured to project the patterned beam onto a target portion of the substrate using a scanning exposure; and a liquid supply system configured provide a liquid, through which said beam is to be projected, to a space between said projection system and said substrate, said liquid supply system comprising: a liquid confinement structure extending along at least a part of the boundary of said space between said projection system and said substrate table, a gas inlet formed in a face of said structure that opposes said substrate to supply gas, a gas outlet formed in a face of said structure that opposes said substrate to extract

gas, an inlet to supply said liquid to said substrate, and an outlet to remove said liquid after said liquid has passed under said projection system.

In an aspect, said liquid supply system provides liquid to only a localized area of said substrate. In an aspect, said area has a periphery conforming to a shape of an image field of said projection system. In an aspect, said inlet supplies said liquid at a first side of said projection system and said outlet removes said liquid at a second side of said projection system as said substrate is moved under said projection system in a direction from the first side to the second side.

While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

The invention claimed is:

1. A liquid confinement structure for a lithographic apparatus, the liquid confinement structure configured to extend along at least a part of a boundary of a space between a projection system of the lithographic apparatus and a movable table of the lithographic apparatus and the liquid confinement structure comprising:

a body defining an aperture arranged to allow a beam of radiation of the projection system to pass therethrough to the space;

a first inlet arranged to supply liquid to the space;

an outlet arranged to remove liquid from the space, an opening of the outlet located outward of the aperture; and

a second inlet arranged to supply gas, an opening of the second inlet located outward of the aperture and of the opening of the outlet.

2. The liquid confinement structure of claim **1**, wherein the aperture has a periphery conforming to a shape of a periphery of a portion of the projection system.

3. The liquid confinement structure of claim **1**, wherein the aperture has a cross-sectional area smaller than the area of a substrate onto which the projection system is configured to project the radiation.

4. The liquid confinement structure of claim **1**, wherein the opening of the outlet and the opening of the second inlet are located in a face of the liquid confinement structure, the face arranged to oppose, when installed in the lithographic apparatus, the movable table.

5. The liquid confinement structure of claim **1**, wherein the liquid confinement structure is configured to form a closed loop around the space and to surround a final optical element of the projection system.

6. The liquid confinement structure of claim **1**, wherein one or more openings of the first inlet are located on opposite sides of a path of the radiation through the space.

7. The liquid confinement structure of claim **1**, wherein a face of the liquid confinement structure comprises a groove enclosing the aperture, the face arranged to oppose, when installed in the lithographic apparatus, the movable table.

8. The liquid confinement structure of claim **1**, further comprising a further outlet arranged to remove fluid from the space, an opening of the further outlet located outward of the aperture, of the outlet, and of the second inlet.

9. A liquid confinement structure for a lithographic apparatus, the liquid confinement structure configured to extend along at least a part of a boundary of a space between a projection system of the lithographic apparatus and a table of the lithographic apparatus movable with respect to the liquid confinement structure and the liquid confinement structure comprising:

a body defining an aperture in a face of the liquid confinement structure, the face arranged to oppose, when installed in the lithographic apparatus, the movable table and the aperture arranged to allow a beam of radiation of the projection system to pass therethrough to the space;

an outlet arranged to remove liquid from the space, an opening of the outlet located in the face and located outward of the aperture; and

an inlet arranged to supply gas, an opening of the inlet located in the face and located outward of the aperture and of the opening of the outlet.

10. The liquid confinement structure of claim **9**, wherein the aperture has a cross-sectional area smaller than the area of a substrate onto which the projection system is configured to project the radiation.

11. The liquid confinement structure of claim **9**, wherein the liquid confinement structure is configured to form a closed loop around the space and to surround a final optical element of the projection system.

12. The liquid confinement structure of claim **9**, further comprising a further outlet arranged to remove fluid from the space, an opening of the further outlet located outward of the aperture, of the outlet, and of the inlet.

13. The liquid confinement structure of claim **9**, wherein the face comprises a groove enclosing the aperture.

14. A liquid confinement structure for a lithographic apparatus, the liquid confinement structure configured to extend along at least a part of a boundary of a space between a projection system of the lithographic apparatus and a table of the lithographic apparatus movable with respect to the liquid confinement structure and the liquid confinement structure comprising:

an aperture through which a beam from the projection system can pass and through which the liquid can pass; and

an inlet arranged to supply liquid to the space above the aperture; and

an outlet arranged to remove liquid, supplied by the inlet, from the space below the aperture.

15. The liquid confinement structure of claim **14**, wherein the aperture has a periphery conforming to a shape of an image field of the projection system.

16. The liquid confinement structure of claim **14**, wherein the liquid confinement structure is configured to form a closed loop around the space and to enclose a final optical element of the projection system.

17. The liquid confinement structure of claim **14**, wherein an opening of the outlet is located in a face of the liquid confinement structure, the face arranged to oppose, when installed in the lithographic apparatus, the movable table, and the opening of the outlet is located outward of the aperture.

18. The liquid confinement structure of claim **14**, further comprising a supply opening located outward of an opening of the outlet, the supply opening arranged to supply a gas.

19. The liquid confinement structure of claim **14**, wherein at least part of the liquid confinement structure is sized and arranged to extend to within a boundary of a surface of a final optical element of the projection system.

20. The liquid confinement structure of claim **14**, wherein one or more openings of the inlet are located on opposite sides of a path of the radiation through the space.

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